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BIOSTRATIGRAPHIC POTENTIAL OF DINOFLAGELLATE CYSTS RECOVERED FROM THE LATE JURASSIC AMMONITES OF THE TETHYS HIMALAYA, INDIA

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ABSTRACT

Ammonites are traditionally known by far to be the most precise and useful biostratigraphic markers for dating, correlation and subdivision of marine Jurassic strata. Extensive work on dinoflagellate cysts from well-dated ammonite-bearing sequences has established their significance as reliable biostratigraphic markers. Stratigraphic ranges of dinoflagellate cyst species have been primarily established through integration with Boreal and European Tethyan ammonoid succession. There is a marked faunal differentiation in Boreal and Tethyan ammonite assemblages during the Late Jurassic. In view of this, integration of known dinoflagellate cyst ranges with Indian ammonite sequences remained somewhat tentative. Moreover, such an attempt also led to suggest indirect correlation between European boreal and Indian Tethyan succession especially during Tithonian/Portlandian, which incidentally still remains tentative and limited.

In order to resolve some of these problems, in-situ index ammonites from the Upper Jurassic successions of the Tethys Himalaya were processed for the recovery of dinoflagellate cysts. Tithonian ammonites, *Kossmatia, Paraboliceras* and *Virgatosphinctes* yielded rich dinocyst assemblages while moderate assemblages were recovered from *Uhligites, Blanfordiceras, Hildoglochiceras* and *Pterolytoceras*. The assemblage, comprising 52 species, includes long- ranging but characteristic Late Jurassic taxa. Species considered stratigraphically significant in the Tethys Himalayan Upper Jurassic successions include *Aldorfia dictyota, Broomea ramosa, B. simplex, Chlamydophorella wallala, Cribroperidinium perforans, Ellipsoidictium cinctum, Endoscrinium granulatum, Gonyaulacysta jurassica, Nannoceratopsis pellucida, Omatia montgomeryi, Productodinium chenii, and Nummus similis* (acritarch). The predominance of Indo-Pacific taxa is conspicuous in the assemblages. Correspondence of the dinoflagellate cyst assemblages with ammonite zonations and possible calibration of the *Omatia montgomeryi* Zone in Tethys Himalaya, Australia and Papua New Guinea Late Jurassic sequences is discussed. A firm correlation of *Hildoglochiceras* Zone (late Lower Tithonian) is established with *Omatia montgomeryi* Zone.

Key words: Dinoflagellate cysts, ammonites, Late Jurassic, Tethys Himalaya.

INTRODUCTION

Investigations of Jurassic dinoflagellate cysts in India were initiated quite late as compared to Europe and elsewhere. The first detailed published account is from the Upper Jurassic Spiti Shale, Kumaon Himalaya (Jain *et al.*, 1984). In general, these initial efforts appeared quite promising in terms of working out successive dinoflagellate cyst assemblages from the classical Spiti Shale succession and their integration with the then available ammonite stratigraphy (Krishna *et al.*, 1982).

Subsequently, Jain *et al.* (1986) and Kumar (1986; 1987a,b) obtained moderately rich dinoflagellate cyst assemblages from the Middle and Upper Jurassic sediments of the Kutch Basin. However, these assemblages were only broadly dated. Precise biozonation could not be attempted due to the lack of availability of ammonite control for integration of dinoflagellate cyst bearing samples, and also due to rather fewer samples from otherwise very thick Jurassic succession of Kutch.

Many of the Jurassic dinoflagellate cyst investigations carried out in Europe are on classical sections having highly refined and accurate ammonite correlation of these assemblages. Further, workable biozonation schemes have also been proposed recognising several marker taxa through their FAD (First Appearance Datum) and LAD (Last Appearance Datum), which are precisely tagged with the boreal ammonite zones (Riding & Thomas, 1992). An analysis of dinoflagellate cyst distribution in the European Jurassic reveals that, in general, their stratigraphic resolution ranges from Stage to Substage level. However, at certain intervals during Kimmeridgian, Portlandian/Tithonian even better precision seems to be possible.

The high degree of provincialism amongst the ammonite fauna during the Late Jurassic has resulted in the establishment of different biozonation schemes for Boreal, Russian Platform and Tethyan regions with the usage of different stage names e.g. Tithonian, Volgian and Kimmeridgian/Portlandian. A precise correlation of ammonite biozones in these regions is still not firmly established, though a few levels are more or less accurately tagged. In view of this, dating based on dinoflagellate cyst ranges defined in terms of boreal ammonite zones are often difficult to integrate with Tethyan and Indo-Pacific ammonite zones. As such, extension of European boreal dinoflagellate cyst ranges to the Indian part of the Tethyan region should be attempted cautiously as some degree of discrepancy has been observed in the stratigraphic ranges of a few species in these regions (Jain *et al.*, 1984). An attempt is made here to resolve this problem by undertaking study of the dinoflagellate cysts recovered from the index ammonite collected from well-dated horizons of the Spiti Shale exposed in the Spiti and the Malla Johar areas of the Tethys Himalaya (Fig.1).

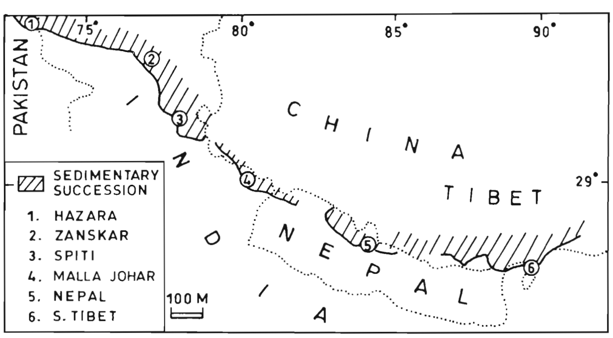


Fig. 1. Main Jurassic-Cretaceous localities of the Tethys Hmalaya.

Our results at first instance appeared to make only a limited advancement in the understanding of the dinoflagellate cyst ranges in Indian vis-a-vis European sequences and also their integration with far more refined ammonite stratigraphy Nevertheless, this work should provide a preliminary database for future studies concerned with dinoflagellate cyst dating and biozonation of the Upper Jurassic successions of the Indo-Pacific region. Undoubtedly the discordant ranges of some dinoflagellate cyst species as compared to Northern Hemisphere (Boreal region) still remain unresolved as these can invariably be attributed to recycling. A major factor that must also be taken into consideration is the possible incompleteness of the present dinoflagellate cyst assemblages due to their highly carbonised state of preservation causing breakage during processing and problems in their proper recovery. Nevertheless, common occurrence of Indo-Pacific taxa is prominently evident in the recovered assemblages. Apparently, Jurassic warmer, shallow epicontinental seas on either side of the relatively deeper, equatorial Tethys could have provided the ideal niche for rapid growth and proliferation of dinoflagellate cysts.

MATERIAL AND METHOD

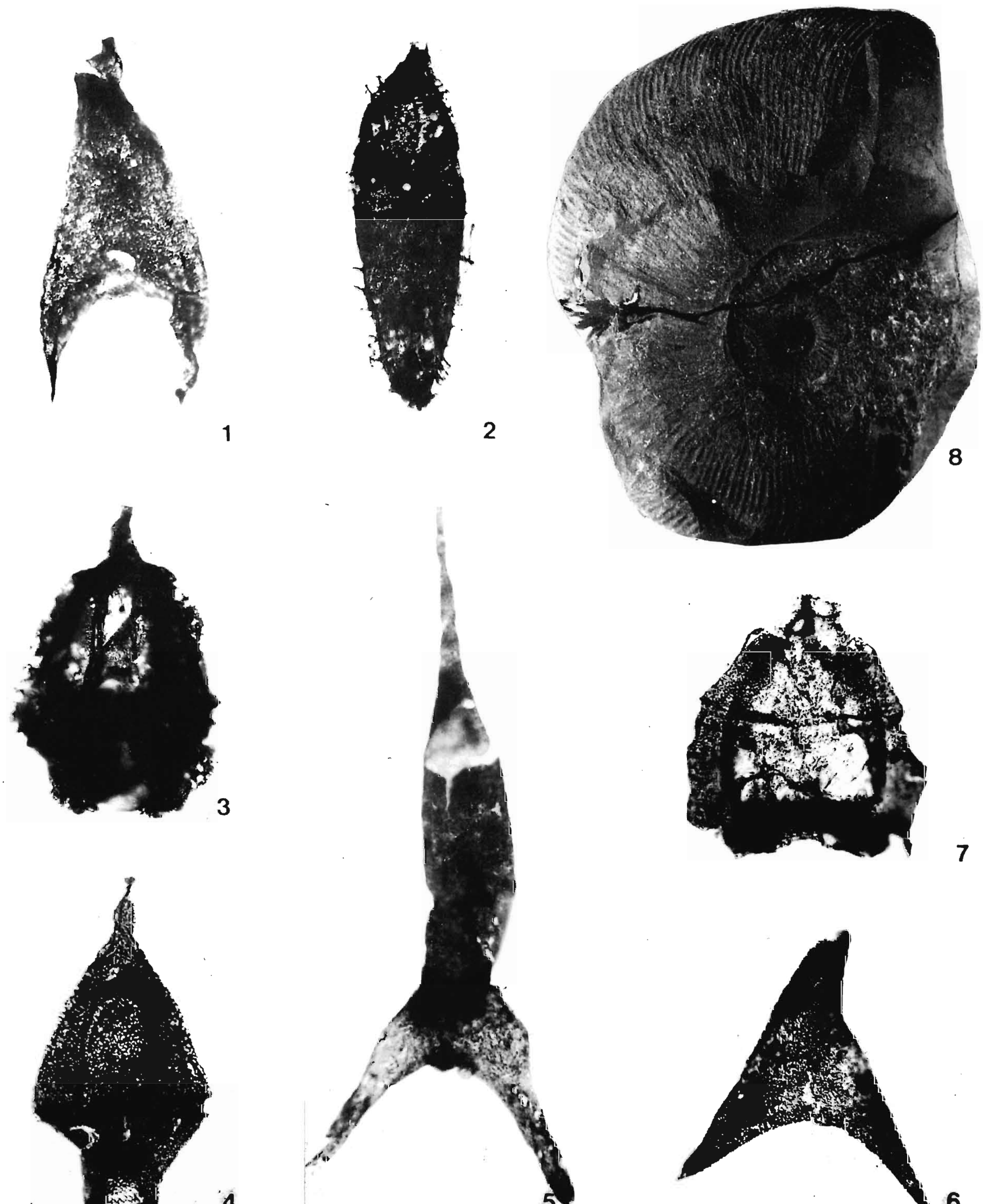
The samples investigated for the present work include 14 ammonite viz., *Aulacosphinctoides, Hildoglochiceras, Blanfordiceras, Uhligites, Kranaosphinctes, Mayaites, Acanthodiscus, Bohemiceras, Spiticeras* from the Malla Johar area and *Pterolytoceras, Kossmatia tenuistriata, Paraboliceras, Virgatosphinctes* and *Pterolytoceras* from the Spiti area, collected by one of us (JK). Of these, only 10 proved to be productive of dinoflagellate cysts. Recovery of dinoflagellate cysts from *Kossmatia, Virgatosphinctes* and

EXPLANATION OF PLATES I →

(All photomicrographs in Differential Interference Contrast, x500)

1. *Nannoceratopsis pellucida* Deflandre 1938 emend. Evitt, 1961; BSIP Slide No. 11041; Coordinates: 136.9 x 18.0.
2. *Omatia montgomeryi* Cookson & Eisenack 1958 emend. Stover & Helby, 1987; BSIP Slide No. 11041; Coordinates: 129.8 x 12.9.
3. *Gonyaulacysta jurassica* (Deflandre) Norris & Sarjeant, 1965 emend. Sarjeant, 1982; BSIP Slide No. 11042; Coordinates: 127.8 x 17.2.
4. *Tubotuberella* sp.; BSIP Slide No. 11041; Coordinates: 127.2 x 15.4.
5. *Broomea simplex* Cookson & Eisenack, 1958; BSIP Slide No. 11042; Coordinates: 123.0 x 21.2.
6. *Nannoceratopsis radiata* Kumar, 1986; BSIP Slide No. 11046; Coordinates: 136.9 x 11.8.
7. *Sirmiodinium grossii* Alberti, 1961 emend. Warren, 1973; BSIP Slide No. 11046; Coordinates: 146.0 x 14.1.
8. *Kossmatia tenuistriata* Gray, 1832, x 1 (in ordinary day light)

Plate I



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Paraboliceras is good while *Uhligites, Hildoglochiceras, Blanfordiceras* and *Pterolytoceras* proved moderately productive. *Aulacosphinctoides, Kranaosphinctes* and *Mayaites*, yielded very poor assemblages and have not been included for the present discussion.

Conventional maceration technique avoiding alkali treatment and acetolysis has been used for the recovery of dinoflagellate cysts and associated organic-walled microfossils from the ammonite. The recovered organic walled microfossils characteristically show a highly carbonised state of preservation, dark brownish black to black in colour and are often quite friable in nature. This was also observed earlier by Pantic *et al.* (1981) and Jain *et al.* (1984) in their study of the Spiti Shale samples. Dinoflagellate cysts with rare acritarchs, spores and pollen primarily dominate the assemblages, besides frequent organic detritus represented by dark, opaque, highly carbonised plant matter.

The type and figures slides of the dinoflagellate cysts are deposited in the museum of the Birbal Sahni Institute of Palaeobotany, Lucknow. For microscopic studies, Olympus BH-2 and Vanox AH-2 microscopes, with Differential Interference Contrast attachments, were used.

CHECKLIST OF DINOFLAGELLATE CYST SPECIES RECOVERED FROM THE AMMONITES

1. *Aldorfia aldorfensis* (Gocht) Stover & Evitt, 1978
2. *A. dictyophora* (Cookson & Eisenack) Davey, 1982
3. *A. dictyota* (Deflandre) Stover & Evitt, 1978
4. ?*Amphorula* sp.
5. *Avellodinium flagellatum* Davey, 1988
6. *Batioladinium* sp.
7. *Belodinium dysculum* Cookson & Eisenack, 1960
8. *Broomea ramosa* Cookson & Eisenack, 1958
9. *B. simplex* Cookson & Eisenack, 1958
10. *Chlamydophorella ambigua* (Deflandre) Stover & Helby, 1987
11. *C. raritubula* Dodekova, 1975
12. *C. wallala* Cookson & Eisenack, 1960
13. *Cleistosphaeridium* sp. A
14. *Cleistosphaeridium* sp. B
15. *Cribroperidinium perforans* (Cookson & Eisenack) Below, 1981
16. *Cyclonephelium densebarbatum* Cookson & Eisenack, 1960
17. *Egmontodinium polyplacophorum* Gitmez & Sarjeant, 1972
18. *E. torynum* (Cookson & Eisenack) Davey, 1979
19. *Ellipsoidictyum cinctum* Klement, 1960
20. *Endoscrinium galeritum* (Deflandre) Vozzhennikova, 1967
21. *E. granulatum* (Raynaud) Lentin & Williams 1981
22. *Energlynia* sp.
23. Forma A
24. Forma B
25. *Gochteodinia* sp. cf. *G. villosa* (Vozzhennikova) Norris, 1978

EXPLANATION OF PLATES II →

(All photomicrographs in Differential Interference Contrast, x500)

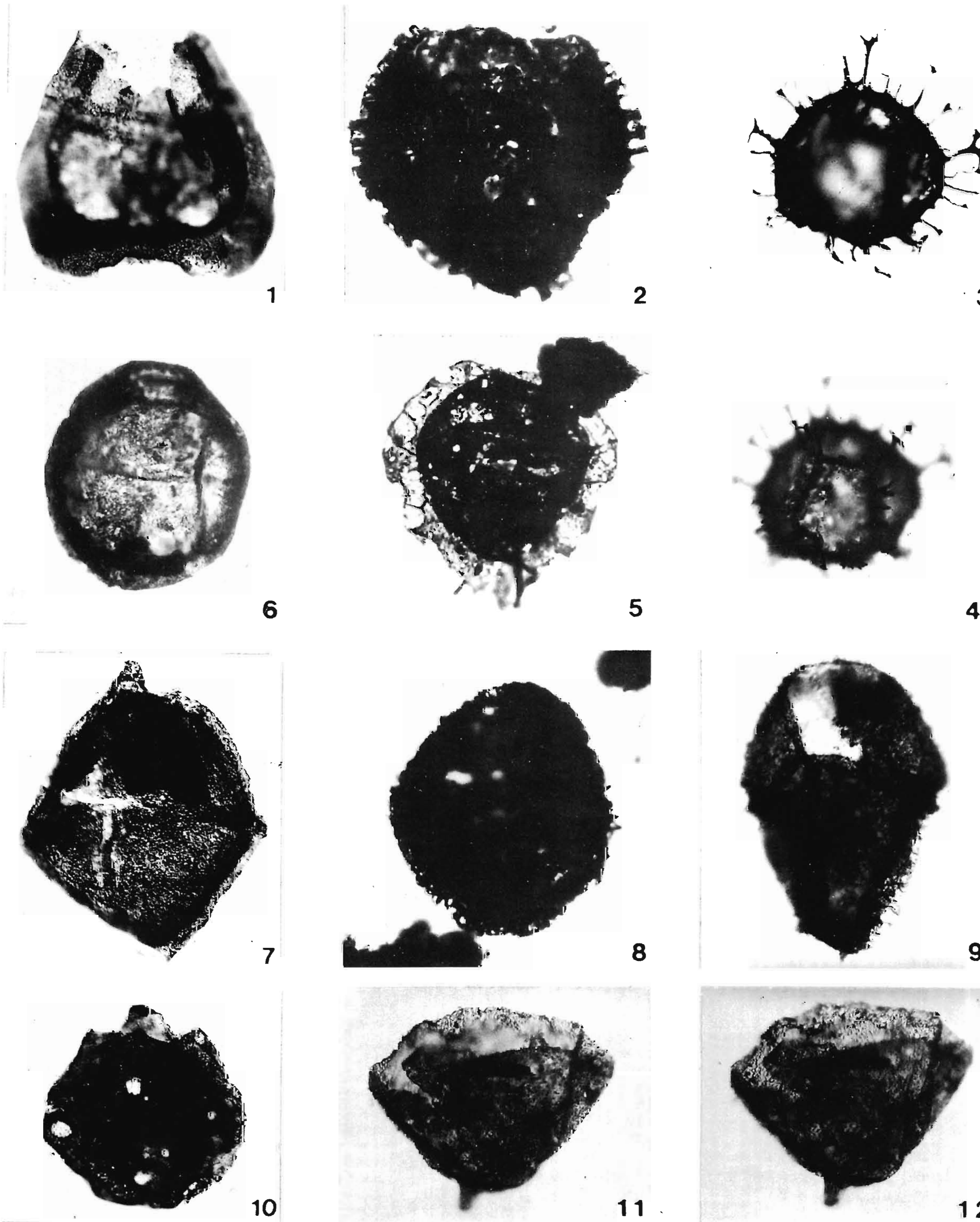
1. *Sirmiodinium grossii* Alberti, 1961 emend. Warren, 1973; BSIP Slide No. 11041; Coordinates: 128.4 x 14.5.
2. *Cyclonephelium densebarbatum* Cookson & Eienack, 1960; BSIP Slide No. 11045; Coordinates: 163.7 x 8.5.

3-4. *Avellodinium flagellatum* Davey, 1988; BSIP Slide No. 11046; Coordinates: 137.8 x 10.6.

5. *Scriniodinium crystallinum* (Deflandre) Klement, 1960; BSIP Slide No. 11046; Coordinates: 156.0 x 21.4.
6. *Nummus similis* (Cookson & Eisenack) Burger, 1980; BSIP Slide No. 11050; Coordinates: 168.8 x 7.0.
7. *Aldorfia dictyophora* (Deflandre) Stover & Evitt, 1978; BSIP Slide No. 11042; Coordinates: 128.6 x 11.9.
8. *Aldorfia aldorfensis* (Gocht) Stover & Evitt, 1978; BSIP Slide No. 11052; Coordinates: 131.4 x 11.7.
9. *Scriniodinium parvimarginatum* (Cookson & Eisenack) Eisenack, 1967; BSIP Slide No. 11046; Coordinates: 142.1 x 18.4.
10. *Forma A*; BSIP Slide No. 11046; Coordinates: 143.3 x 10.9.

11-12. *Energlynia* sp.; BSIP Slide No. 11039; Coordinates: 8.0 x 152.0.

Plate II



26. *Gonyaulacysta jurassica* (Deflandre) Norris & Sarjeant emend. Sarjeant, 1982
27. ?*Lagenorhytis delicatula* (Duxbury) Duxbury, 1979
28. *Lagenorhytis* sp.
29. *Leptodinium* sp. cf. *L. hyalodermopse* (Cookson & Eisenack) Stover & Evitt, 1978
30 *Mendicodinium granulatum* Kumar, 1986
31 *Mombasadinium parvelatum* (Jiang) Riding & Helby 2001
32. *Nannoceratopsis pellucida* Deflandre 1938 emend. Evitt 1961
33. *N. radiata* Kumar, 1986
34. *Nummus similis* (Cookson & Eisenack) Burger, 1980
35. *Omatia montgomeryi* Cookson & Eisenack, 1958 emend. Stover & Helby, 1987
36. *Pareodinia ceratophora* Deflandre, 1947 emend. Gocht, 1970
37. *Pareodinia* sp. A
38. *Pareodinia* sp. B
39. *Peridictyocysta mirabilis* (Cookson & Eisenack) Cookson & Eisenack, 1974
40. *Productodinium chenii* Davey, 1988
41. *Prolixosphaeridium capitatum* (Cookson & Eisenack) Singh 1971
42. *P. granulosum* (Deflandre) Davey *et al.*, 1966
43. *P. mixtispinosum* (Klement) Davey *et al.*, 1969
44. *Rigaudella aemula* (Deflandre) Below, 1982
45. *Rigaudella* sp. cf. *R. filamentosa* (Cookson & Eisenack) Below, 1982
46. *Scriniodinium crystallinum* (Deflandre) Klement, 1960
47. *S. parvimarginatum* (Cookson & Eisenack) Eisenack, 1967
48. *Sirmiodinium grossii* Alberti, 1961 emend. Warren, 1973
49. *Tubotuberella apatela* (Cookson & Eisenack) Ioannides *et al.*, 1977
50. *T. eisenackii* subsp. *oligodentata* (Cookson & Eisenack) Stover & Evitt, 1978
51. *Tubotuberella* sp.
52. *Wanaea digitata* Cookson & Eisenack, 1958

AMMONITES AND RECOVERED DINOFLAGELLATE CYST FLORA

Kossmatia Uhlig, 1907

(Pl. I, fig.8)

The genus *Kossmatia* Uhlig (1907) was described from the Middle Division of the Spiti Shale (Formation), Tethyan Himalaya. Arkell *et al.* (1957) suggested its stratigraphic range as Kimmeridgian to Upper Tithonian, while Enay (1973) interpreted it to be restricted to Upper Tithonian. Based on the study of the Spiti Shale succession in Malla Johar area,

EXPLANATION OF PLATES III →

(All photomicrographs in Differential Interference Contrast, x500)

1. *Gonyaulacysta jurassica* (Deflandre) Norris & Sarjeant emend. Sarjeant, 1982; BSIP Slide No. 11046; Coordinates: 153.7 x 17.3.
2. *Nannoceratopsis pellucida* Deflandre 1938 emend. Evitt,1961; BSIP Slide No. 11053; Coordinates: 133.8 x 7.6.

3-4. *Tubotuberella apatela* (Cookson & Eisenack) Ioannides *et al.*, 1977; (3) BSIP Slide No. 11044; Coordinates: 139.6 x 7.0; (4) BSIP Slide No. 11054; Coordinates: 136.6 x 9.0.

5-6. *Tubotuberella eisenackii* sub sp. *oligodentata* (Cookson & Eisenack) Stover & Evitt, 1978; BSIP Slide No. 11049; Coordinates: 148.4 x 6.3.

7. *Pareodinia ceratophora* Deflandre, 1947 emend. Gocht, 1970; BSIP Slide No. 11045, Coordinates: 124.3 x 19.4.

8,11. *Mombasadinium parvelatum* (Jiang) Riding & Helby, 2001.; 8. BSIP Slide No. 11044;Coordinates: 127.0 x 5.6. 11. BSIP Slide No. 11045; Coordinates 141.0 x 23.7.

9-10. *Chlamydophorella wallala* Cookson & Eisenack, 1960; 9. BSIP Slide No. 11044; Coordinates: 158.2 x 4.7; 10. BSIP Slide No. 11042; Coordinates: 152.3 x 20.3.

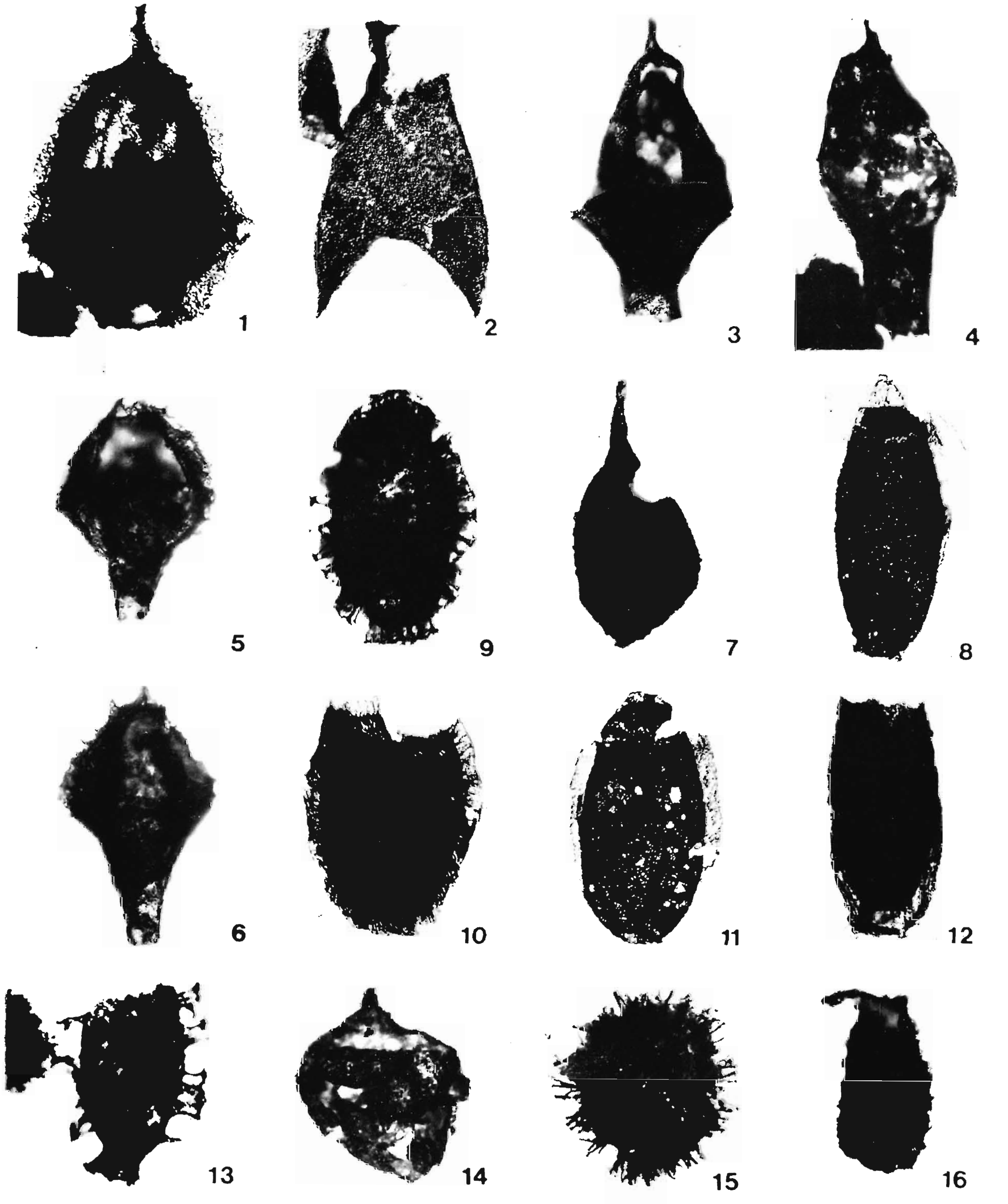
12. *Belodinium dysculum* Cookson & Eisenack, 1960; BSIP Slide No. 11044; Coordinates: 145.5 x 19.0.

13. ?*Amphorula* sp.; BSIP Slide No.11046; Coordinates: 140.4 x 5.7.

14. *Lagenorhytis delicatula* (Duxbury) Duxbury, 1979 emend Piasecki, 1984; BSIP Slide No. 11040; Coordinates: 145.9 x 3.1.

15. ?*Cleistosphaeridium* sp. B; BSIP Slide No. 11052; Coordinates: 141.0 x 11.5.

16. ?*Gochteodinia* sp cf. *G. villosa* (Vozzhennikova) Norris, 1978; BSIP Slide No. 11045; Coordinates: 153.6 x 18.2.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Krishna *et al.* (1982) established the age of *Kossmatia* to range from *Hildoglochiceras-Virgatosphinctes* Assemblage Zone to the overlying *Himalayites-Corongoceras-Aulacosphinctes* Assemblage Zone.

Mouterde (in Bordet *et al.*, 1971) recovered *Kossmatia tenuistriata* and *K. desmidoptycha* from Nupra Formation in Thakkhola region of Nepal Himalaya, correlatable with the Spiti Shale, and placed these ammonite at the basal part of the Upper Tithonian. Westernmann (in Gradstein *et al.*, 1989, p. 63) has documented *Kossmatia* sp. along with *Aulacosphinctoides* sp. and *Katroliceras* sp. from Nupra Formation and dated it to be lower Tithonian. Pathak and Krishna (1993, fig.5) have assigned Lower Tithonian age on the basis of its occurrence and simultaneous appearance with *Aulacosphinctoides* (see Krishna and Pathak, 1994). In the boreal realm this interval broadly corresponds to the *Elegans* Zone-*Pectinatus* Zone interval.

Kossmatia is known from northern Pakistan, Spiti, Malla Johar, Nepal, southern Tibet, Indonesia, New Guinea, New Zealand, Australia, Antarctica, Europe, North Africa, Syria, Caucasus, California, Texas, Madagascar and western India. However, species of the Himalayan belt and SW Pacific region are different from those occurring in other parts of the world and NE Pacific regions.

The specimen of *Kossmatia tenuistriata*, which has yielded the dinoflagellate cysts, was collected by one of us (JK) from the Middle division of the Spiti Shale exposed in the Kibber Section of the Spiti Valley.

The following 34 dinoflagellate cyst species have been recovered from *Kossmatia* : *Aldorfia dictyophora, A. dictyota, Amphorula* sp., *Avellodinium flagellatum, Belodinium dysculum, Broomea simplex, Chlamydophorella ambigua, C. wallala, Cleistosphaeridium* sp. A., *Egmontodinium torynum, Endoscrinium galeritum, E. granulatum, Gochteodinia* sp. cf. *G. villosa, Gonyaulacysta jurassica, Mendicodinium granulatum, Mombasadinium pavelatum, Nannoceratopsis pellucida, N. radiata, Nummus similis, Omatia montgomeryi, Pareodinia ceratophora, Peridictyocysta mirabilis, Productodinium chenii, Prolixosphaeridium*

EXPLANATION OF PLATES IV →

(All photomicrographs in Differential Interference Contrast, x500)

1,6. *Amphorula* sp.; (1) BSIP Slide no. 11046; Coordinates: 135.6 x 10.5, (6) BSIP Slide No. 11044; Coordinates: 149.0 x 8.5.

2. *Chlamydophorella wallala* Cookson & Eisenack, 1960; BSIP Slide No. 11044; Coordinates: 158.6 x 20.7.

3. *Peridictyocysta mirabilis* (Cookson & eisenack) Cookson & Eisenack, 1974; BSIP Slide No. 11041; Coordinates: 145.2 x 14.7.

4-5. *Endoscrinium granulatum* (Raynaud) Lentin & Williams, 1981; BSIP Slide No. 11046 Coordinates: 128.3 x 20.7.

7. *Ellipsoidictyum cinctum* Klement, 1960; BSIP Slide No. 11047; Coordinates: 153.7 x 5.0.

8. *Cleistosphaeridium* sp. A; BSIP Slide No. 11041; Coordinates; 124.o x 21.0.

9. *Egmontodinium polyplacophorum* Gitmez & Sarjeant, 1972; BSIP Slide No. 11048; Coordinates: 144.2 x 3.9.

10. *Chlamydophorella raritubula* Dodekova, 1975; BSIP Slide No. 11044; Coordinates: 149.2 x 18.0.

11. *Pareodinia* sp.A; BSIP Slide No. 110; Coordinates: 149.6 x 5.0.

12. *Egmontodinium torynum* (Cookson & Eisenack) Davey, 1979; BSIP Slide No. 11045; Coordinates: 136.2 x 17.3.

13. *Evansia* sp.; BSIP Slide No. 11045; Coordinates: 138.0 x 20.8.

14. *Chlamydophorella ambigua* (Deflandre) Stover & Helby 1987; BSIP Slide No. 11044; Coordinates: 160.0 x 10.6.

15. *Prolixosphaeridium granulosum* (Deflandre) Davey *et al.*, 1966; BSIP Slide No. 11044 Coordinates: 136.5 x 12.6.

16. *Prolixosphaeridium mixtispinosum* (Klement) Davey *et al.*, 1969; BSIP Slide No. 11044; Coordinates; 145.1 x 19.4.

17. *Endoscrinium galeritum* (Deflandre) Vozzhennikova, 1967; BSIP Slide No. 11045; Coordinates: 131.8 x 6.9.

18. *Tubotuberella* sp.; BSIP Slide No. 11041; Coordinates: 139.2 x 8.9.

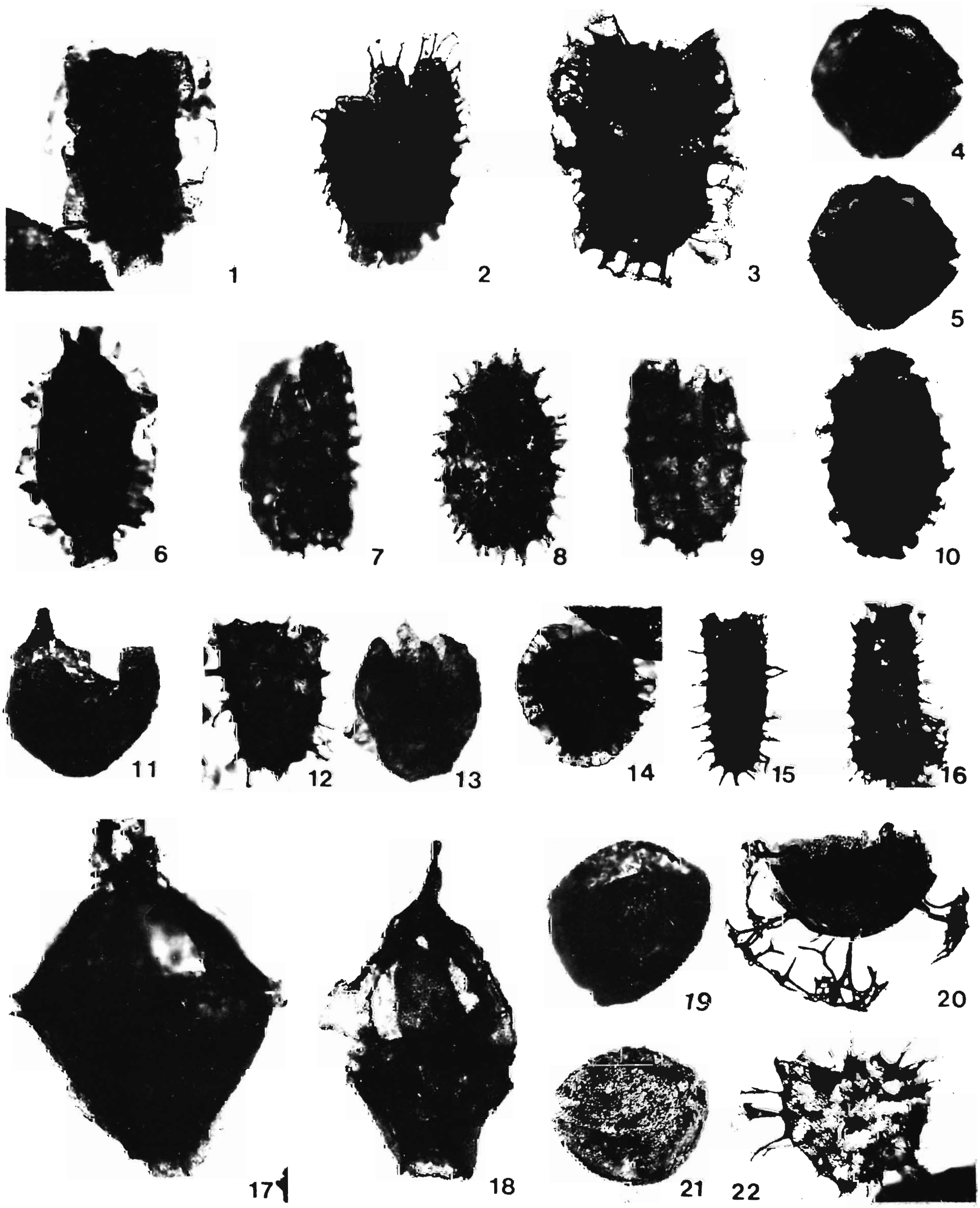
19. ?*Lagenorhytis* sp.; BSIP Slide No. 11055; Coordinates: 147.7 x 8.9.

20. *Rigaudella filamentosa* (Cookson & Eisenack) Below, 1982; BSIP Slide No. 11046; 148.0 x 11.6.

21. *Mendicodinium granulatum* Kumar, 1986; BSIP Slide No. 11044; Coordinates: 129.9 x 6.8.

22. *Egmontodinium torynum* (Cookson & Eisenack) Davey, 1979; BSIP Slide No. 11044; Coordinates: 135.7 x 13.5.

Plate IV



capitatum, P. granulosum, P. mixtispinosum, Rigaudella aemula, Rigaudella sp. cf. *R. filamentosa, Scriniodinium parvimarginatum, Sirmiodinium grossii, Tubotuberella apatela and Tubotuberella* sp. An acritarch *Veryhachium* sp. and few spores are also recorded.

Virgatosphinctes Uhlig, 1910

(Pl. V, fig.3)

The genus *Virgatosphinctes* was erected by Uhlig (1910), describing its several species from the Middle Division of Spiti Shale in Tethys Himalaya. Arkell *et al.*, (1957) documented its stratigraphic range as Lower to Upper Tithonian. Its distribution is now considered to be restricted in the Upper Tithonian. In terms of the standard Tethyan ammonite chronozones, it approximates to *Microcanthum* and *Durangites* zones. The corresponding range in standard boreal scheme would be from *Pallasoides* Zone to *Glaucolithus* Zone interval. The stratigraphic range of *Virgatosphinctes* is best known in Kutch where it occurs in association with *Micracanthoceras micracanthum* in the *Micracanthum* Zone of Early Upper Tithonian. However, it also occurs in underlying sediments in Lakhapur section in Kutch (Krishna *et al.*, 1995) and in Chichin section in Spiti (Pathak & Krishna, 1993, fig.3).

Virgatosphinctes has a very wide geographic distribution in the Indian subcontinent viz, Jaisalmer, Kutch, Pakistan and Tethyan Himalaya (Ladakh-Zanskar, Spiti, Kumaon, Nepal, southern Tibet). Outside the southern margin of the Tethys (North Africa, East Africa, Madagascar), Indonesia, New Guinea, Australia and New Zealand.

Occurrence of *Virgatosphinctes* outside this region is now discounted and forms previously assigned to it from Argentina and elsewhere have been transferred under a separate genus confined to Lower Tithonian (Dr. Leanza pers. communication with JK).

The specimen that has yielded the dinoflagellate cyst assemblage was collected from the upper level of the Middle Division of the Spiti Shale from the Gate Section of Spiti Valley by one of us (JK). However, this particular specimen is characterised by a much narrower umbilicus as compared to most of the known species of *Virgatosphinctes* with which it compares well in the rib framework, possibly representing the most involute form of the diverse *Virgatosphinctes* suite.

The dinocyst flora recovered from this ammonite specimen is represented by the following 14 species: *Avellodinium flagellatum, Egmontodinium polyplacophorum, E. torynum, Endoscrinium galeritum, Evansia evittii, Gonyaulacysta jurassica, Mendicodinium granulatum, Nannoceratopsis pellucida, Nummus similis, Omatia montgomeryi, Peridictyocysta mirabilis, Rigaudella aemula, Scriniodinium crystallinum* and *Tubotuberella apatela.*

EXPLANATION OF PLATES V →

(All photomicrographs in Differential Interference Contrast, x500)

1-2. *Paraboliceras,* x 2.

3. *Virgatosphinctes,* x1.

4. *Rigaudella aemula* (Deflandre) Below, 1982; BSIP Slide No. 11046; Coordinates 142.3 x 18.7.

5. *Chlamydophorella raritubula* Dodekova, 1975; BSIP Slide No. 11044; Coordinates: 136.0 x 9.0.

6. *Productodinium chenii* Davey, 1988; BSIP Slide No. 11045; Coordinates 130.5 x 16.7.

7. *Pareodinia* sp.B; BSIP Slide No. 11051; Coordinates: 127.9 x 12.8.

8. *Chlamydophorella ambigua* (Deflandre) Stover & Evitt, 1987; BSIP Slide No. 11045; coordinates: 129.4 x 14.7.

9. *Belodinium dysculum* Cookson & Eisenack 1960; BSIP slide No. 11044; Coordinates : 126.8 x 13.0.

10. *Nummus similis* (Cookson & Eisenack) Burger, 1980; BSIP Slide No. 11044; Coordinates: 151.0 x 16.8.

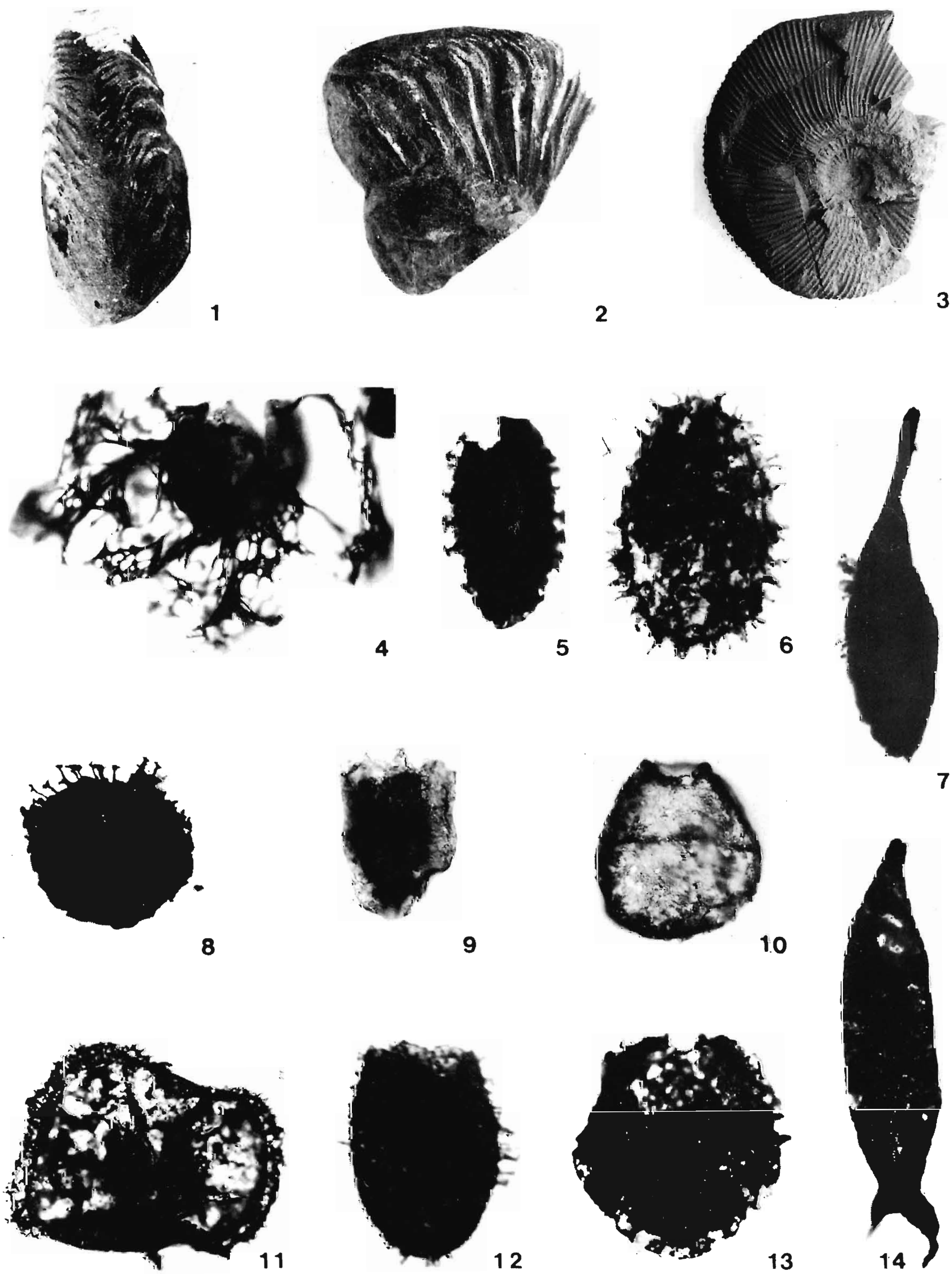
11. *Wanea digitata* Cookson & Eisenack, 1958; BSIP Slide No. 11056; Coordinates: 120.7 x16.3.

12. *Prolixosphaeridium capitatum* (Cookson & Eisenack) Singh, 1971; BSIP Slide No. 11045; Coordinates: 105.5 x 11.8.

13. *Aldorfia dictyota* (Cookson & Eisenack) Davey, 1982; BSIP Slide No. 11044; Coordinates: 137.2 x 18.9.

14. *Broomea ramosa* Cookson & Eisenack, 1958 emend. Lentin & Williams, 1976; BSIP Slide No. 11044; Coordinates: 129.0 x 5.0.

Plate V



Paraboliceras Uhlig, 1910

(Pl. V, fig. 1-2)

The genus *Paraboliceras* Uhlig (1910) was established for a group of species characterised by parabolic ribs and narrow smooth band on the venter, collected from High Himalaya, New Guinea and Indonesia. Its stratigraphic range is Kimmeridgian to Upper Tithonian (Arkell *et. al.*, 1957). Krishna *et al.* (1982) and Krishna (1983) assigned *Paraboliceras* to the *Himalayites - Corongoceras - Aulacosphinctes* assemblage Zone of Upper Tithonian age. Pathak and Krishna (1993) have extended its range through the entire Tithonian (*Hydonotum* Zone to *Durangites* Zone).

The *Paraboliceras* specimens were collected from the upper part of the Middle division of the Spiti Shale Formation by one of us (JK) from Kibber and Ghete sections of the Spiti Valley and Laptal Section of Malla Johar area of Kumaon Himalaya. However, out of these 3 specimens from three different regions, a fragmentary specimen (Pl. 5 Fig. 1-2) collected from the Ghete section proved to be rich in dinocysts. The assemblage is represented by the following 23 species:

Aldorfia aldorfensis, Amphorula sp., *Broomea simplex, Chlamydophorella ambigua, C. raritubula. C. wallala, Cleistosphaeridium* sp. A, *Cribroperidinium perforans, Endoscrinium galeritum, Evansia evittii, Gonyaulacysta jurassica, Lagenorhytis* sp., *Leptodinium* sp. cf *L. hyalodermopse, Mendicodinium granulatum, Nannoceratopsis pellucida, Omatia montgomeryi, Pareodinia ceratophora, Pareodinia* sp., *Scriniodinium crystallinum, S. parvimarginatum,*

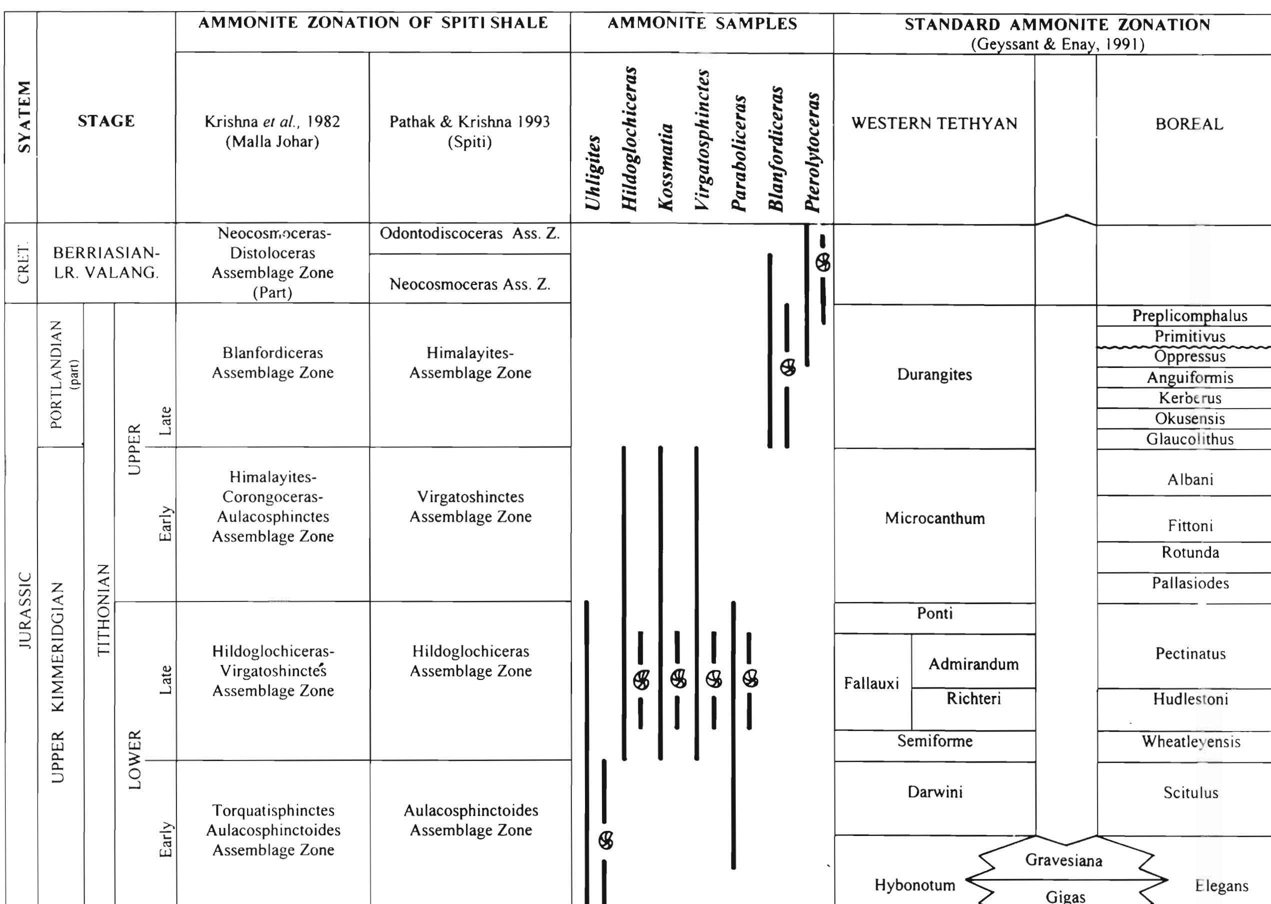


Fig. 2. Stratigraphic ranges and levels of the studied ammonites with respect to the zonation schemes.

Sirmiodinium grossi, Tubotuberella apatela and *Wanaea fimbriata*.

Blanfordiceras Cossman, 1907

The genus *Blanfordiceras* Cossman (1907) is very widely distributed in southern Europe, North Africa, Madagascar, Salt Range, Tethys Himalaya, southern Tibet, Indonesia, Australia, New Guinea, Mexico, Peru and Argentina. Jai Krishna (unpublished data) documented rare presence of *Blanfordiceras* in the basal part of Umia Member of Umia Formation in a section north of Lakhapar in the Kutch basin. It is dated to be Upper Tithonian, corresponding to the Standard Tethyan *Microcanthum* and *Durangites* zones. In Kumaon and Spiti areas of Tethys Himalaya, it is one of the most frequently found taxon represented by several species, especially in the late Upper Tithonian *Blanfordiceras* Assemblage Zone of Krishna *et al.* (1982). It is also documented from the upper levels of Nupra Formation of Thakkhola area, Nepal (Gradstein *et al.*, 1989, p. 63). Pathak and Krishna (1993) assigned it Upper Tithonian age.

Dinoflagellate cyst assemblage recovered is poor, represented by the following 10 species:

Aldorfia aldorfensis, Batioladinium sp., *Cribroperidinium perforans, Chlamydophorella ambigua, Endoscrinium galeritum, Evansia evittii, Leptodinium* sp. cf. *L. hyalodermopse, Nannoceratopsis pellucida, Omatia montgomeryi*, and *Scriniodinium crystallinum*.

Uhligites Roman, 1938

The genus *Uhligites* Roman (1938) is restricted to Tithonian (Arkell *et al.*, 1957). Geographically it is confined to the Tethys Himalayan belt, Indonesia, New Zealand, Madagascar and Central America. Krishna *et al.* (1982) have documented it from Lower Tithonian *Torquatisphinctes - Aulacosphinctoides* Assemblage Zone from the Laptal section of Kumaon Himalaya, corresponding to *Darwini* to *Ponti* Zone of standard Tethyan scheme. In the boreal realm, its stratigraphic range approximates to *Scitulus* Zone to *Pectinatus* Zone. Pathak and Krishna (1993) assigned it Lower Tithonian to early part of Upper Tithonian age. The

S. No.	TAXA \ AMMONITE	KOSMATIA	PARABOLICERAS	VIRGATOSPHINCTES	PTERLYTOCERAS	BLANFORDICERAS	UHLIGITES	HILDOGLOCHICERAS
1.	*Aldorfia aldorfensis*		•		•	•	•	•
2.	*A. dictyphora*	•						
3.	*A. dictyota*	•						
4	?*Amphorula* sp.	•	•					
5	*Avellodinium flagellatum*	•		•				
6	*Batioladinium* sp.					•		
7	*Belodinium dysculum*	•						
8	*Broomea ramosa*	•			•			
9	*B. simplex*	•	•					•
10	*Chlamydophorella ambigua*	•	•			•	•	
11	*C. raritubula*	•	•					
12	*C. wallala*	•	•					
13	*Cleistosphaeridium* sp. A	•						
14	*Cleistosphaeridium* sp. B		•					
15	*Cribroperidinium perforans*		•			•		
16	*Cyclonephelium densebarbatum*				•		•	
17	*Egmontodinium polyplacophorum*			•				
18	*E. torynum*	•		•	•		•	
19	*Ellipsoidictyum cinctum*				•			
20	*Endoscrinium galeritum*	•	•	•		•		
21	*E. granulatum*	•						
22	*Energlynia* sp.				•			
23	*Forma* A		•	•		•		
24	*Forma* B	•						
25	*Gochteodinia* sp. cf. *G. villosa*	•						
26	*Gonyaulacysta jurassica*	•	•	•				
27	*Lagenorhytis delicatula*				•			
28	?*Lagenorhytis* sp.		•					
29	*Leptodinium* sp. cf. *L. hyalodermopse*		•			•		
30	*Mendicodinium granulatum*	•	•	•				
31	*Mombasadinium parvelatum*	•						
32	*Nannoceratopsis pellucida*	•	•	•		•		
33	*N. radiata*	•						
34	*Nummus similis*	•		•	•		•	•
35	*Omatia montgomeryi*	•	•	•		•		
36	*Pareodinia ceratophora*	•	•		•			
37	*Pareodinia* sp. A		•		•			
38	*Pareodinia* sp. B							•
39	*Peridictyocysta mirabilis*	•		•			•	
40	*Productodinium chenii*	•						
41	*Prolixosphaeridium capitatum*	•			•			
42	*P. granulosum*	•						
43	*P. mixtispinosum*	•			•			
44	*Rigaudella aemula*	•		•				
45	*Rigaudella sp.* cf. *R. filamentosa*	•						
46	*Scriniodinium crystallinum*		•	•		•		
47	*S. parvimarginatum*	•	•					•
48	*Sirmiodinium grossii*	•	•					
49	*Tubotuberella apatela*	•	•	•			•	
50	*T. eisenackii* subsp. *oligodentata*						•	
51	*Tubotuberella* sp.	•						
52	*Wanaea digitata*		•					

Fig. 3. Dinoflagellate cyst distribution in the studied ammonites from Tethys Himalaya.

specimen which has yielded the dinoflagellate cyst assemblage was collected from the lower part of the Middle division of the Spiti Shale from the Laptal Section, Malla Johar area, Kumaon Himalaya.

The moderate dinoflagellate cyst assemblage recovered from *Uhligites* consists of following 8 species:

Aldorfia aldorfensis, Chlamydophorella ambigua, Cyclonephelium densibarbatum, Egmontodinium torynum, Nummus similis,

AMMONITES	HORIZON	LOCATION	ZONE	AGE	DIAGOSNOSTIC DINOCYTS
Blanfordiceras Cossman 1907	Upper part of Upper Division of Spiti Shale	Laptal Section, Malla Johar area, Tethys Himalaya	*Blanfordiceras* Assemblage Zone	Late Upper Tithonian	*Aldorfia aldorfensis, Batioladinium* sp., Forma A, *Cribroperidinium perforans*
Paraboliceras Uhlig 1910	Upper part of Middle Division of Spiti Shale	Ghette Section, Spiti Valley, Tethys Himalaya	*Hildoglochiceras-Virgatosphinctes* Assemblage Zone	Tithonian	*Broomea simplex, Chlamydophorella wallala, Gonyaulacysta jurassica, Omatia montgomeryi, Cribroperidinium perforans*
Virgatosphinctes Uhlig 1910	Upper part of Middle Division of Spiti Shale	Ghette Section, Spiti Valley, Tethys Himalaya	*Hildoglochiceras Virgatosphinctes* Assemblage Zone	Late Lower Tithonian	*Egmontodinium polyplacophorum, E. torynum, Gonyaulacysta jurassica, Omatia montgomeryi, Peridictyocysta mirabilis*
Kossmatia Uhlig 1910	Upper part of Middle Division of Spiti Shale	Kibber Section, Spiti Valley, Tethys Himalaya	*Hildoglochiceras Virgatosphinctes* Assemblage Zone	Late Lower Tithonian to Early Upper Tithonian	*Aldorfia dictyota, Broomea ramosa, B. simplex, Gonyaulacysta jurassica, O. montgomeryi, Peridictyocysta mirabilis, Mombasadinium parvelatum*
Uhligites Spath 1927	Upper part of Middle Division of Spiti Shale	Laptal Section, Malla Johar area, Tethys Himalaya	Upper part of *Torquatisphinctes-Aulacosphinctoides* Assemblage Zone	Lower Tithonian to Early Upper Tithonian	*Egmontodinium torynum, Peridictyocysta mirabilis, Tubotuberella apatela*
Pterolytoceras Spath 1927	Upper part of Upper Division of Spiti Shale	Ghette Section, Spiti Valley, Tethys Himalaya	*Blanfordiceras* Assemblages Zone to *Neocosmoceras-Distaloceras* Assemblage Zone	Upper Tithonian to Valanginian	*Broomea ramosa, Egmontodinium torynum, Lagenorhytis delicatula*
Hildoglochiceras Spath 1927	Upper part of Middle Division of Spiti Shale	Laptal Section, Malla Johar area, Tethys Himalaya	*Hildoglochiceras Virgatosphinctes* Assemblage Zone	Late Lower Tithonian	*Broomea simplex, Broomea* sp., *Aldorfia aldorfensis*

Fig. 4. Location and stratigraphic position of ammonites and their diagnostic dinoflagellate cysts.

Peridictyocysta mirabilis, Tubotuberella apatela and *Tubotuberella eisenackii* subsp. *oligodentata.*

Pterolytoceras Spath, 1927

The genus *Pterolytoceras* Spath (1927) was described from the Upper division of Spiti Shale of High Himalaya. It has been dated as Valanginian in age with suspected occurrence also in late Upper Tithonian (Arkell *et al.*, 1957, p. 196). It is considered to belong to the upper part of the *Blanfordiceras* Zone of Krishna *et al.* (1982) corresponding to the *Durangites* Zone (late Upper Tithonian) and post- *Durangites* Zone (Berriasian-Valanginian) in terms of Standard Tethyan Scheme. The present specimen was collected from the upper levels of the Upper division of Spiti Shale.

The dinoflagellate cyst assemblage recovered is moderate, represented by the following 12 species:

Aldorfia aldorfensis, Broomea ramosa, Cyclonephelium densibarbatum, Egmontodinium torynum, Ellipsoidictyum cinctum, Energlynia sp., *Nummus similis, Pareodinia ceratophora, Pareodinia* sp.A, *Prolixosphaeridium capitatum* and *P. mixitispinosum.*

Hildoglochiceras Spath, 1927

Hildoglochiceras Spath (1927) was described from the Middle Division of Spiti Shale from High Himalaya. It is Middle Tithonian (late Lower Tithonian according to current concepts) in age.

The specimen treated for dinoflagellate cyst study was collected from the middle part of the Middle Division of Spiti Shale, Laptal Section of Malla Johar area, Kumaon Himalaya. Detailed work on Kimmeridgian-Tithonian ammonite biostratigraphy by one of us (JK) has revealed that *Hildoglochiceras* occurs together with *Aulacosphinctoides* in Lakhapar area, Kutch, western India. It is stratigraphically older than *Virgatosphinctes densiplicatus* group. The only precise occurrence of *Hildoglochiceras* in Kutch is restricted to the post-*Hybonotum* Zone part of the upper part of Lower Tithonian (=Middle Tithonian of the three fold division). It has not been recovered from the definite Upper Tithonian. Accordingly, Pathak & Krishna (1993) assigned middle to late Lower Tithonian age to *Hildoglochiceras*, corresponding to *Rajnathi* Zone to *Virgatosphinctes* Zone interval, which in turn is broadly equivalent to *Semiforme* Zone to *Ponti* Zone interval.

The dinoflagellate cyst assemblage recovered from *Hildoglochiceras* specimen is extremely meagre, represented by *Broomea simplex, Broomea* sp., *Aldorfia aldorfensis, Scriniodinium parvimarginatum* alongwith a few unidentifiable fragmentary dinoflagellate cyst specimens and the acritarch *Nummus similis*.

DISCUSSION

An exhaustive study on the morphologic, taxonomic and stratigraphic aspects of the Jurassic dinoflagellate cysts was done by Sarjeant (1978). Sarjeant (1967, 1975, 1979) and Riley & Sarjeant (1972) correlated dinoflagellate cyst ranges with Standard Ammonite Zonation that resulted in the compilation of the dinoflagellate cyst range charts tagged with ammonite biozonation. Subsequent studies by Woolam & Riding (1983), Riding (1984), Riding & Thomas (1992) and Herngreen *et al.* (1988) established workable biozonation schemes along with recognition of several dinoflagellate cyst marker species by tagging their FAD and LAD with boreal ammonite zones. Riding & Thomas (1992) highlighted the potential of several dinoflagellate cyst taxa to serve as excellent index fossils, due to their wide geographic distribution in the northern Hemisphere.

Studies of Jurassic dinoflagellate cysts carried out from India, Australia and Papua New Guinea (Jain *et al.*, 1984; Helby *et al.*, 1987; Davey, 1988) laid emphasis on integration with available ammonite or other molluscan evidences. Jain *et al.*, (1984) noted association of typical Indo-Pacific (or Southern Hemisphere) and Northern Hemisphere taxa in the Malla Johar section of Spiti Shale and highlighted their biostratigraphic potential with reference to the Indo-Pacific ammonites of the Tethys Himalaya. However, they overlooked the possibility of recycling of Lower Tithonian *Omatia montgomeryi* assemblage into the Upper Tithonian *Blandfordiceras* Zone levels, which raised doubts about the authenticity of the section and ammonite correlations (Stover *et al.*, 1996, p. 659). Recycling of the dinoflagellate cysts became evident when Spiti Shale data was compared with the Australian zonation of Helby *et al.* (1987). It is now apparent that the dinoflagellate cyst assemblage of the sample L-21 in the Spiti Shale succession, containing *Pseudoceratium spitiensis* is typical of the *P. iehiense* Zone in Australasia, and occurrence of *O. montgomeryi* in the sustantially younger horizons (sample L-31) is due to recycling. Throughout the Indo-Pacific region, *P. iehiense* zone assemblages occur higher than and separate from the *O. montgomeryii* zone assemblages (Robin Helby, personal communication). Further, dinoflagellate cyst dating of the Late Jurassic Australian and Papua New Guinea successions differed greatly, despite attempts for calibration of dinoflagellate cyst zones in both the schemes (see Davey, 1988, p.5, fig. 3). Discrepancies in dinoflagellate cyst age determinations of these two regions still remain unresolved (Stover *et al.*, 1996).

Stratigraphic levels of the studied ammonites viz. *Kossmatia, Virgatosphinctes, Paraboliceras, Uhligites, Hildoglochiceras, Blanfordiceras* and *Pterolytoceras* have been calibrated with ammonite zonations of Tethys Himalaya, western Tethys and Boreal region (Fig. 2). The dinoflagellate cyst assemblages recovered from these seven ammonites (Fig. 3) generally contain long ranging but characteristic Upper Jurassic species, besides several significant diagnostic forms (Fig. 4). The occurrence of several species common to Tethys Himalaya, Australia and Papua New Guinea demonstrate the distinct Indo-Pacific character of these assemblages. The assemblages from Tethys Himalaya (India) have an additional significance because of the remarkable co-occurrence of Australian (Southern Hemisphere) and typical boreal (Northern Hemisphere) dinoflagellate cyst taxa.

At least four species e.g. *Belodinium dysculum, Cribroperidinium perforans, Egmontodinium polyplacophorum* and *Peridictyocysta mirabilis* are supposed to have appeared at the base of Tithonian (or Kimmeridgian/ Tithonian boundary corresponding to the base of *Aulacosphinctoides* Assemblage Zone). However, they are now known to extend at least into the upper *D. swanense* Zone (Kimmeridgian) in australia (Robin Helby, personal communication). *Endoscrinium granulatum* appears at the base of Scitulus Zone in the North Sea type area (Raynaud, 1978). Its FAD in Scitulus Zone corresponds to the upper part of *Aulacosphinctoides* Assemblage Zone of early Lower Tithonian age in the Indian Tethyan succession. Next important event in Tithonian dinoflagellate cyst assemblages is the appearance of *Omatia montgomeryi* in the late Lower Tithonian.

Omatia montgomeryi appears to be one of the most significant species for the identification of late Lower Tithonian in the Indo-Pacific region. Helby *et al.* (1987) and Stover & Helby (1987) stated that total stratigraphic range of *O. montgomeryi* from Australia and Papua New Guinea is restricted within Lower Tithonian *O. montgomeryi* Zone, younger to the *Cribroperidinium perforans* Zone of the basal Tithonian. Common and consistent occurrence of *O. montgomeryi* in the ammonites belonging to the *Hildoglochiceras* Assemblage Zone of late Lower Tithonian age in different localities of the Tethys Himalaya (present study) strengthens this view. However, rare occurrence of *O. montgomeryi* in the late Upper Tithonian ammonite *Blanfordiceras* is considered due to reworking. *O. montgomeryi* is supposed to be commonly reworked into younger sediments in Australia (Helby *et al.*, 1987) and in Papua New Guinea. According to Stover & Helby (1987), even the type specimen of *O. montgomeryi* described by Cookson & Eisenack (1958) was recycled from the underlying *O. montgomeryi* Zone. Accordingly, its occurrence in the *Blanfordiceras* Zone in Malla Johar area above *Psuedoceratium spitiensis*, associated with *Hildoglochiceras* Zone (Jain *et al.*, 1984) is attributed to recycling.

The present study establishes a firm correlation between dinoflagellate cyst assemblage of *O. montgomeryi* Zone and *G. jurassica* Zone of Australia and Papua New Guinea with the dinoflagellate cyst assemblages of the *Hildoglochiceras* Assemblage Zone of late Lower Tithonian in the Tethys Himalayan successions. For correlation purposes, *O. montgomeryi* can be taken as the standard point of reference for tagging early part of late Lower Tithonian in the Indo-Pacific region. This may facilitate interpretation of Davey's (1988) correlations with Australian Zones of Helby *et al.* (1987) to some extent. Helby *et al.* (1987) established the *O. montgomeryi* zone comparing with molluscan evidences (ammonites, bivalves). In the present study, occurrence of *O. montgomeryi* has a direct correlation with *Hildoglochiceras* zone ammonites late Lower Tithonian age. These evidences within the Indo-Pacific realm help to confirm age calibration with ammonite data.

Broomea simplex having its first appearance in *O. montgomeryi* Zone in Papua New Guinea is also documented here from *Hildoglochiceras* Zone. *Broomea ramosa* makes its appearance earlier than *B. simplex* in early Lower Tithonian as evident from its occurrence in Papua New Guinea (Davey, 1988). It is significant to note that *B. ramosa* has been recorded from *Ritcheri* Zone of late Lower Tithonian in Swiss Jurassic succession (Monteil, 1993).

Occurrence of *Gonyaulacysta jurassica* with *O. montgomeryi*, first recorded by Jain *et al.* (1984) from Spiti Shale of Malla Johar, Tethys Himalaya, has now been documented more or less consistently from other areas of Tethys Himalaya as well as from Papua New Guinea. In European Jurassic sequences, although *G. jurassica* has been recorded from *Pectinatus* Zone (Riley, 1979), its records younger to *Elegans* Zone (equivalent to basal Tithonian) are considered to be the result of reworking (Riding & Thomas, 1992). However, its consistent occurrence in ammonite samples from upper part of the *Hildoglochiceras* Assemblage Zone from different areas of Tethys Himalaya suggests extension of its stratigraphic range up to the top of late Lower Tithonian that may possibly be equated with *Pectinatus* Zone of the Boreal realm.

Productodinium chenii, common to Papua New Guinea and Tethys Himalaya, has its LAD coincident with that of *G. jurassica* (Davey,1988). *Chlamydophorella wallala* is another characteristic species at this level, endemic to Tethys Himalaya and Papua New Guinea. Presently recorded from the upper part of *Hildoglochiceras* Assemblage Zone, *C. wallala* has its LAD slightly younger to *G. jurassica* in Papua New Guinea, which in our opinion is likely to fall in the basal part of the early Upper Tithonian.

CONCLUSIONS

1. Dinoflagellate cysts recovered from well-dated ammonites from the Tethys Himalaya reveal

their biostratigraphic potential in age determination and correlation of the Tithonian successions in the Indo-Pacific region.

2. Dinoflagellate cyst assemblages from ammonites of the *Hildoglochiceras* Zone are assigned to *O. montgomeryi* and *G. jurassica* Zones of Papua New Guinea.

3. Correspondence of *Omatia montgomeryi* Zone and *Gonyaulacysta jurassica* Zone of Papua New Guinea and Australia with the upper part of the *Hildoglochiceras-Virgatosphinctes* Zone of Krishna *et al.* (1982) and *Hildoglochiceras* Zone of Krishna & Pathak (1993) of late Lower Tithonian age in Tethys Himalaya is suggested.

4. Tethys Himalayan dinoflagellate cyst assemblages show a distinctive Indo-Pacific character. Occurrence of some characteristic Boreal and European Tethyan species are also recorded, suggesting co-occurrence of Northern and Southern Hemisphere dinoflagellate cysts in this part of the Tethyan realm.

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